DURATION, ENERGY AND EXTENT OF REACTION MOVEMENTS — SIMPLE AND FLYING REACTIONS

By Frank Angell

The following investigation is in continuation of the "Preliminary note" on reaction times and of the description of the "trigger" reaction-key in an earlier number (Vol. 22) of this magazine. The key described there was a self-registering spring-balance which gave the extent and strength as well as the time of the reaction movement. In addition the key could be set for different initial tensions so as to show the relation of variations in tension to extent and time of the reaction movement.

With the one reagent employed it was found that there was no constant ratio existing between the length of the reaction-time and the strength (and length) of the reaction-pull, and that consequently the increase in reaction time found for increased initial tension was probably owing not to the time spent in generating stronger reaction impulses, but to the increased drag of the key on the reaction movement.

In the meantime Isserlin's interesting and meritorious analysis of curves of simple voluntary motion [1] appeared which besides taking up the question from the physiological side, has covered considerable of the ground projected by the writer in the 'preliminary note.'

The essential feature of Isserlin's work is the analysis of the curve of the reaction movement traced on a kymograph, the movement being the flexing in a horizontal plane, of the first joint of the fore-finger. For this purpose the finger was made fast to the lower side of a light aluminum wheel, vertically pivoted, the axis of the wheel being in line with the pivot of the joint. Around the rim of the wheel ran a fine silk thread to a pointer sliding on a vertical track in contact with the kymograph, the thread being held taut by a light spiral spring. Adding to this a fork and an Ach card-changer, Isserlin read directly from the tracing on the drum the time, form and extent of the reaction-movement. The reaction-time in this arrangement was read from the space between the mark of the simulus (card-changer) and the point where the reaction curve left the horizontal line on the drum.

[1] Max Isserlin: Ueb. d. Ablauf einfacher willkürlichen Bewegungen. Kräpelin's Psy. Arb. B. VI, Heft I.

It would have perhaps been better if the time of reaction had been given by a time marker so as to show any error which might come from the stretching of the thread in the reaction movement. Isserlin states that this error was 'negligible' as measurements showed that the pointer passed through practically the same space as a point on the periphery of the wheel. It would have been well to give these measurements and likewise the tension on the thread for maximum motions. If, as is probable, the measurements were taken by slowly moving the wheel around certain angular distances and noting the corresponding spaces passed over by the pointer, the results would hardly be normative for the sharp, quick sweep of the finger in the actual reaction movement. It is certainly not easy to see how a thin silk thread, not far probably, from a meter and one-half long, passing around a wheel and over two pulleys and pulling against the friction of the track and against a spiral spring, should not have been stretched by a sharp movement of some 6 or 7 centemeters.

The part of Isserlin's work with which we are more immediately concerned is entitled "Die Einstellung in ihren Beziehungen zur Bewegung" (S. 86) and as the title, implys, it is devoted to investigating the relation existing between the reaction 'attitude' on the one side, to the time and the forms of the reaction curve on the other.

Agreeing with Ach that the "problem" determines the way of reacting — that the distinction between muscular and sensorial reactions is the difference between the determination to react as quickly as possible and to react after obtaining a more or less full knowledge of the stimulus—I. finds the reaction curve a better index of the reagent's attitude than the reaction time; for while one may draw valid conclusions from the distribution curves of reaction times, each single reaction curve is a legible index of the attitude which determines it. In the sensorial reaction the motion is slower and the curve flatter than is the case with the muscular form. Reagents whose curves show a strong development of motor energy are 'muscular' in their attitude; weaker curves come from sensorially 'set' reagents. The curves showing greater energy follow the shorter reaction times.

As before stated, the present investigation is a continuation of the work with the trigger reaction key to further inquire into the relations of length and strength of pull to other factors entering into reactions. In order to directly compare the results with Isserlin's the index of the key was connected with a lightly running ergograph pointer in contact with a Balthzar drum. Some little trouble was experienced with the cord

connecting the key index with the carriage of the pointer on account of its tendency to stretch with the longer pulls. Finally a fine steel wire (strand of a picture wire) was used, linked to a short length of braided silk line where the cord passed around a pulley on its way to the carriage. The stretching of the cord made no difference in the time relations of a reaction, as the beginning of the reaction movement was signaled by the break of a contact on the key; but it would have made a difference in the shape of the first part of the reaction curve. As the lightest pull in our experiment was 100 grams, there was more of a drag on the cord than in Isserlin's work. Consequently the pointer was adjusted at the beginning of each day's experiments and not infrequently, in the course of a day's series. The minimum pull of 100 grams came in part from the friction of the pointer carriage, but mainly from a spiral spring of sufficient strength to prevent backlash, with the long quick pulls; it also served to bring back the carriage to its starting point.

The stimulus was given from a telephone placed behind and a little to the right of the reagent. Beyond this came the Morse key which sounded the false stimulus occasionally employed. None of the apparatus save the reaction key and a section of the connecting cord could be seen by the reagents.

In the first month of experimentation four reagents were busied in the work, but those were reduced to two, partly on account of the time required to take down the reagents introspections, and work out the curves, but mainly because in experiments where the introspections are often developed, from a viva voce exchange of question and answer between reagents and operator, it was felt that the former must not only have had considerable experience in reacting, but must be well enough acquainted with the operator to be 'objective' in answering his questions — a condition which is by no means a matter of course as between students and instructor. That is to say, the two reagents chiefly employed, Miss Lanktree (L) and Mr. Coover (C), were thoroughly interested in the work and at the same time had acquired sufficient laboratory 'standing' to feel independent of any 'leading questions' which the operator might be unlucky enough to put to them. On the other side the operator was careful to avoid giving the impression that he expected anything from the reagents save the "plain unvarnished tale" or indeed that any 'tale' at all was necessarily expected. With G. E. Muller's reflections on the danger of "Vielfragerei,"[2] the writer is in hearty accord.

[2] G. E. Muller. Zur Analyse d. Gedachtnisstatigkeit u. d. Vorstellungverlaufes. S. 122.

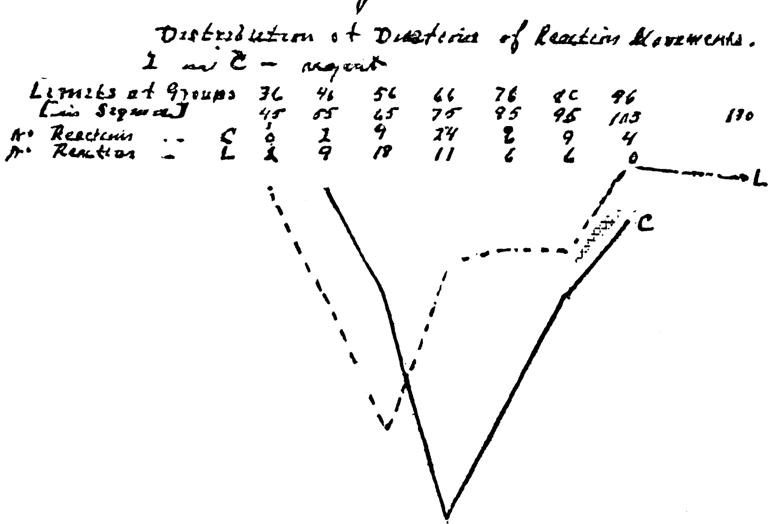
Duration of the Reaction Movement

The first part of Isserlin's work is taken up with the problem of the rebound or backlash (Rucktoss) from a quick movement, but into this matter we cannot go, because in our experiments the course of the backlash was obscured by the tension of the springs against which the reaction-movement was made —a tension running from 100 to 2,200 grams. But this resistance serves to bring out in a stronger light a constancy in the duration of the reaction movement independent of its extent — a condition found by Binet and Courtier[3] in their investigation of hand writing and further developed by Isserlin who formulates it in a rule to the effect that the entire duration of movements remains constant for each person regardless of changes in its course.

In the writer's experiments enough reactions were taken with L. and S. to make possible a graphic illustration of this constancy in the time of movement by means of distribution curves. These Curves are given in Fig. 1.

Had the abscissa units been 5 sigma instead of 10, the curve of L. would have shown a second maximum near the mark of 90, due to slowness of movement resulting from unfamiliarity

Fig. 1



³ Rev. Philos., 35.

with the key on the second day of experimentation. The results of the first day are not included as they were not gotten under the same conditions as the rest.

But in any case the results are noteworthy and unexpected by reagents and experimentor. Of C's total of 54 movements, 52 fall within a compass of 40 sigma, and of L's 53, 5r fall within the same limits. Looking at the results more in detail, one finds that 6 of L's movements falling on 4 different days, take 60 sigma. The measurements are probably not far from correct, for with the Balthzar drum running on high gears, the tuning-fork curves were spread enough to enable one to read thirds of 0.01 sec. with ease. Consequently the actual times must have been between 59 and 60 sigma.

But these motions lasting 60 sigma vary in extent from 6.5 to 20 millimeters. Moreover the initial tension of the springs against which the reaction took place varied from 200 to 700 grams; the strength of reaction-pull ran approximately[4] from 450 to 1,250 grams, and the reaction times ranged between 97 and 157 sigma with an average of 119 and a. m. v. of 14. In the case of C. we find that 24 reactions lie within the duration limits of 60 to 70 sigma. They were taken on 7 different days against initial resistances of 100, 400, 600, 700 and 850 grams, varied in extent of movement from 9 to 45 millimeters and in strength of pull from 300 to 1,925 grams. The reaction times for 21 (for various reasons three could not be read) ranged from 113 to 313 sigma with an average of 159 and a m. v. of 23.

It is obvious that if there is any correspondence existing between the attitude of the reagent and the reaction-times, there is none indicated between attitude and duration of movement. As a matter of fact, the various instructions given — "React energetically," "React with a short sharp motion," "React naturally, as quickly as possible,"— are not reflected in the duration of movement so that perhaps in it we have the nearest approach to a straight physiological factor that enters into the reaction process. Indeed, these results remind one of Sherrington's diagram of the "scratch reflex" of the spinal dog where variations in the intensity of stimulation are answered more by variations in the extent and velocity of the flexion movement than by changes in its duration.[5]

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[4] The "approximately" results from 2 springs attached respectively to the key and the carriage. Hence the total strength of pull had to be determined by another spring balance—a procedure which allows a considerable play of error.

[5] Sherrington, Intergrative Action of the Nervous System, p. 73.

The Course of the Reaction Movement in Relation to the Instructions. Secondary Impulses

The instructions given to the reagents were mainly in two forms, viz.:

(1). React naturally as quickly as possible.

(2). React energetically as soon as your hear stimulus.

In the course of a sitting, 4 or 5 reactions under one form of instruction were succeeded by as many under the other, the appropriate instruction being given emphatically, with few exceptions, before each movement.

A few reactions (not included in the quantitative statements of the preceding paragraph) were carried out by reagent C. under the instruction: "As soon as you hear stimulus, react quickly and gently."

For L. the instruction ran: "React shortly and quickly as soon as you hear stimulus." At the beginning other forms were given such as "React as quickly as possible with a short sharp pull," or "React as quickly as possible with a long, quick motion": but as interpreted by the reagents in the reaction process they were covered by the 3 forms given above — "short and sharp pull" working out as "quick and gentle" and "long and quick" as "energetic." But the change from a series with the instruction to "React naturally as quickly as possible" to "React energetically as soon as you hear stimulus" was a step of increased but not excessive difficulty, requiring usually a more elaborate preparation in the pre-period. "React energetically" supplemented "react quickly" in the reagents attitude but "react quickly" and "react as soon as possible" result in about the same attitude.

In the case of L. and C., the determination once made to react "naturally" or "energetically" was "set aside" ready for use and the reagents gave themselves up to the reception of the stimulus, trusting that the reaction movement would follow automatically — which was usually the case. But despite the automatic character of the reaction, the determination to react "energetically" made itself manifest both in quickness of response and extent of movement. Eighteen (18) of L's natural reactions taken towards the end of the investigation gave: median, 119,— average, 117 (m. v. 9). Thirteen (13) energetic reactions gave median 107.5—average, 109 (m. v. 8). For C., 23 natural reactions gave median 157—average, 166 (m. v. 33); 20 energetic reactions gave median, 146.5—average 150 (m. v. 21).

The reactions of L. and C. would hardly have fitted into

the traditional forms of muscular and sensorial reactions: L. in her reception of the stimulus was decidedly sensorial; she rarely responded to the false stimulus (click of an electric signal), and in the rare cases where a false reaction took place, there was no lengthening of the succeeding reaction-time. When a false stimulus was given, L. usually recognized it as "false at the time" whereas C. often reacted and then felt as if he had "reacted to nothing." Still it seems that L. reacts to the intensity component of the stimulus rather than to its quality: she notes repeatedly "the impact of the sound" and asserts she trys to make the appearance of the sound and the reaction movement coincide. Now her reactions were quick (natural 117, energetic, 107.5), quicker than those of the so-called muscular type. They were also automatic, i. e. the satisfactory apperception of the stimulus was followed, without effort by the appropriate natural or energetic reaction.

The course of C's reactions was towards the muscular form until checked by a false reaction. As an experienced reagent he quickly dropped from a full to a schematic apperception of the stimulus. The analogy he used to explain this was that of "significant," versus proof-reading. False reactions threw him back into a minute apperception of the stimulus with an increase of about 100 sigma in reaction-time. Usually he carefully imaged the reaction movement and then "set it aside." In case of a genuine discriminative reaction (between real and false stimulus) he notes the reaction movement is automatic. In the course of time he comes to take a spatial property of the stimulus as determining factor. (The telephone was placed slightly behind and to one side of his right ear). This factor he characterizes as "a knowledge of the form of the stimulus as articulated and referred to the right ear as recipient organ." The reaction movement was automatic, but "the extent did not sometimes correspond to the intention of the pre-period." But C's reactions, even when his apprehension of the stimulus was most abstract and therefor nearest the muscular type were longer than those of the sensorially reacting L.

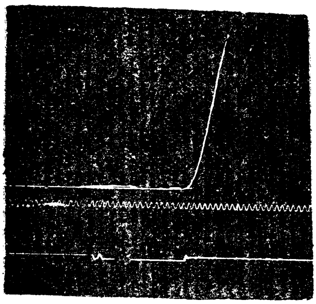
In order to analyze the reaction curve in successive moments (1/100 sec.) of its course, the kymographic tracings were placed in a reflectoscope and their images, magnified about 7 times, were reflected on drawing paper. These enlarged reflections were then carefully traced with lead-pencil and the tracings taken to the drawing-board for measurement.

The curves are not directly to be compared with those of Isserlin on account of the rapidly increasing resistance applied in our experiments, though despite this difference there is

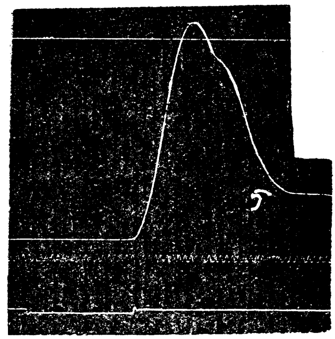
considerable likeness in the typical curve of both investigations.

Typical forms of the reaction curve are given in Fig. 2.

FIG. 2.



R. t. 164 sigma
Duration of motion — 100 sigma.
Length of pull, 38, 5m. m.



R. T. 184 sigma
Duration of motion — 115 sigma
Length of pull, 47m. m.

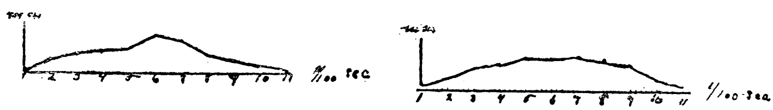
By means of the enlargement, one is able to measure with a fair degree of accuracy the distances passed over by the reaction movement in successive hundredths of a second. For the two curves above distances are:

1-100 Sec.	M. M.
1.	0.27
2.	2.08
3.	3.70
4.	4.50
5.	5.00
6.	7.60
7.	6.10
8.	3.90
9.	2.70
10.	1.40
11.	0.55
	37.80

1-100 sec.	M. M.
1.	1.1
2.	2.4
3.	4.5
4.	5.0
5.	6.4
6.	6.2
7.	6.9
8.	5.7
9.	5.2
10.	2.7
11.	1.2
	47.3

The discrepancy between the direct measurement on the length of pull and the sum of component pulls comes from the rounding out of decimals.

The graphs for the above figures picturing the distances pulled as function of successive units of time (1/100 sec.) are given in Fig. 3.



But while Fig. 2 shows the typical form of reaction curve for all reagents, there were not infrequent deviations from this form arising from causes in part physical and in part physiological. In a few cases, the reagent seemed to be dissatisfied with the extent or strength of pull and voluntarily pulled again. More frequently, however, the curves showed a sharp break in their course, resulting from a period of total rest or even period of relaxation followed by a secondary reaction not noticed by the reagent. Thus reagent L. after the instruction to " React energetically as quickly as possible " gave a reaction movement in 96 sigma which ended after a period of 60 sigma, passing a distance of 9mm with a pull of 475 grams. This was followed by a moment of rest lasting between 10 and 20 sigma when a new impulse was started which lasted 57 sigma, passing over a distance of 16mm with a pull of 900 grams. The reagent's introspections give no indication of knowledge of this double pull except that it was " thought the pull was small." Similarly C. after a reaction time of 160 sigma, pulling for 68 sigma over a distance of 35 mm, paused for 20 sigma and then pulled 10 mm further. These secondary reactions, following the primary after an interval of from 10 to 30 sigma remind one of the " incremental reflex " in Sherrington's experiments[6] though it is to be remembered that these movements in our experiments met the uniformly increasing tension of a spring as well as the energizing variations in the muscle.

Whatever the nature of these secondary movements, they raise the question of the length of reaction-time when the reacting member is already in motion. More specifically,—What will be the effect on the time of reaction if the stimulus acts after the pulling motion has begun?—a question which also follows logically W. G. Smith's investigation of " Antago-

[6] *Op. c.* p. 75.

nistic Reactions "[7] where it was found that for some reagents, in the ordinary break reaction, the antagonistic effect ranged from 40 to 50 sigma. To answer the above question, the reagents were directed to draw themselves together as usual at the ready-signal, next to begin a gentle flexion of the reacting finger at the command "Pull"! and finally to "react as quickly as possible" when they heard the stimulus — these directions being repeated for each reaction. But it soon became evident that the ready signal would have to be dropped as it seemed to serve as a stimulus for which the preliminary pull was the answering reaction. Accordingly the starting of tuning-fork and drum came to serve as signal, after which the command Pull! was given, followed about half a second later by the stimulus from the telephone.

A difficulty which at first appeared serious resulted from the conflict in consciousness of the direction to begin a gentle pull and then follow it with a quick reaction to the stimulus: the intent to give a gentle initial pull acted as a strong distraction from the motive of the reaction movement proper in the earlier trials of the experiment. But surprisingly soon the preliminary pull became a matter of mechanical routine and seemed to exercise no distractive influence whatever. But to say that the motive for the preliminary pull had become inoperative because not noticed would be going too far. For an incident which took place on the 7th day of the experiment showed clearly that a state which the reagent through repetition had ceased to notice might become operative in opposition to the reaction.

On this day the operator started the drum as usual, gave the command Pull! and sounded the stimulus, neglecting however to start the tuning-fork, the outcome being that the reagent failed to react altogether. He did not know that he had not reacted, did not know that the tuning-fork had not sounded: he simply felt that something out of the way had happened but could not tell what. Inquiry showed that it was not a case of suspension of movement through surprise, but through the lack of one element of the reaction motive which the reagent had long ceased to notice. The next day, under like conditions, the reagent responded to the stimulus, though not aware that the tuning-fork was at rest: his only comment was that the interval seemed very short. In general, for most of the flying reactions, after the preliminary flexion had become mechanical, the command Pull! seemed to serve merely as a ready signal for the stimulus.

[7] W. G. Smith, Antagonistic Reactions. Mind, N. S. XII, 47. Vid. also Judd, McAllister and Steele, *Psy. Rev. Mon.* Sup. I, 131.

The reagents for this part of work were Coover (C.) who had served in the earlier stage of the investigation, W. Root (R.) who had shown himself a careful and dependable observer and the writer (A.).

TABLE 1

SIMPLE AND FLYING REACTIONS FOR REAGENTS C., R. AND A.

	Simple Reactions			Flying Reactions		
Date	Number	Average (σ)	Median (σ)	Number	Average (σ)	Median (σ)
REAGENT A.						
Feb. 19	10	178	155	8	127	116
" 21	8	210	220	8	151	145
" 23	10	186	191	10	106	106
" 26	10	157	177	10	108	104
March 6	5	188	178	7	146	144
REAGENT R.						
Nov. 25	4	168	160	10	117	114
" 27	6	169	165	4	119	119
" 29	7	163	161	7	170	140
Dec. 6	..	...	...	6	117	116
" 8	6	168	165	9	113	114
" 11	7	153	150	7	114	115
" 13	4	149	146	10	127	124
REAGENT C.						
Jan. 19	7	171	160	8	125	125
" 22	8	155	153	8	116	118
" 24	11	148	155	9	123	125

TABLE 2

TEN QUICKEST REACTIONS—SIMPLE AND FLYING [S or F]

R.		*C.*		*A.*	
S	F	S	F	S	F
136	60	130	92	120	65
135	98	130	95	120	85
135	99	140	106	130	86
140	100	140	110	130	88
143	102	142	110	140	90
143	102	142	110	147	93
145	105	150	110	150	96
145	110	150	112	155	97
149	110	156	112	155	100
155	110	150	115	158	102

Table 1 and 2 give the figures for simple and flying reactions for each day's experimentation, and it shows almost, without exception that the flying reactions are quicker than the simple, even though moving against a stronger tension of the springs. The sole exception appears in the third series for reagent R, where two of the 7 cases gave uncommonly high figures. It

may be surmised that these two are the result of a conflict between the motives for the preliminary pull and the reaction proper such as frequently occurred at the beginning of this form of reaction. But in the absence of any note concerning them in the reagents introspections, they had to be taken up into the average. The median probably gives the more dependable value and this is smaller than the corresponding value for the simple reaction. The difference between the two forms of response is clearly brought out by the columns giving the 10 quickest movements for each of the several reagents.

A superficial inspection of the figures in this table might give rise to the impression that the flying reaction was a shorter variety of the shortened or muscular form, and that its relation to the latter was akin to that existing between the shortened and the complete reaction—the 3 forms thus making a sort of quantitative series of preparation or innervation of the reacting muscle. But opposed to this we find from the introspections that the flying reaction is more like the complete than the shortened form in most cases in requiring a strong and distinct voluntary impulse: in fact, the change from the slow preliminary pull to the sharp, hard reaction movement proper, is more distinct than the impulse which follows the apperception of the stimulus in many complete reactions.

Further we note on the physiological side, that the complete and flying reaction show a greater resemblance in the form of the kymographic tracings of the reaction movement. Isserlin[8] found that the kymographic tracing of the complete reaction slanted more from the perpendicular than that of the shortened form. This difference, which he considered characteristic was of course, due to the greater velocity of the shortened reaction movement in part or all of its course. A similar statement holds true for the relation between the flying and the shortened reaction movements: the flying reaction movements are relatively slower as was obvious from a casual look at the curves on the smoked paper. Taking the average velocities of the two forms of an hour's experimentation near the close of the work, when the flying reaction might reasonably be supposed to have arrived at a minimum of mental friction, one gets the following figures:

COMPARISON OF AVERAGE VELOCITIES (M. M.-PER 0.01 SEC.) OF SIMPLE AND FLYING REACTIONS

Reagent	No.	Simp.	No.	Fl'g.
C........	7	3.5	7	2.3
R........	15	2.9	11	2.7
A........	9	4.1	10	3.3

[8] *Op. cit. S.* 96.

To what are these results due? The writer thinks that for the most part, we have here to do with physiological factors. Haycraft[9] has given quantitative expression to a well known fact viz.: that a reaction movement is discharged with greater velocity if started from a detent than from a normal condition of agonistic-antagonistic equilibrium. Now while in most shortened (muscular) reactions there is no external hindrance to the beginning of the movement, the agonistic and antagonistic muscles governing the flexion and extension of the reacting member are in more or less state of excitation as was shown not infrequently in our experiments in the not infrequent pulling apart of the contacts in the interval between the ready signal and the stimulus contraction. In the flying reaction the antagonistic muscle is already relaxed by the preliminary pull — a condition which would naturally bring out the most noticeable marks of these movements, viz: the slower motion and the quicker reaction.

Taking the differences between the medias for the simple and flying reactions we find that for A. the figures range from 34 to 85 sigma (5 series), for R. from 25 to 46 sigma (6 series) and for C. from 22 to 46 sigma (3 series). It is not improbable that these values represent the periods of antagonistic relaxation in simple reaction movements.

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[9] Haycraft Upon the Production of rapid voluntary movements. *Jour. of Phys.* 23.